Interference Estimation for Multicarrier Systems

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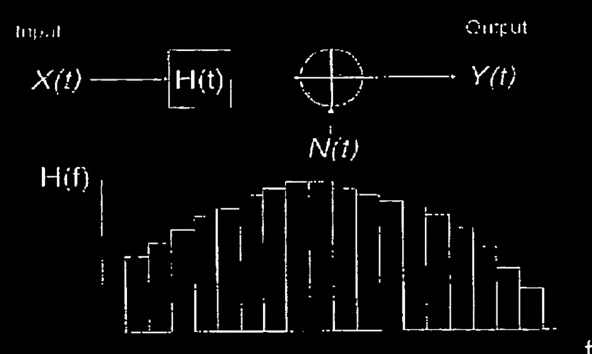
Outline

- Aggregate Interference
- Interference Coupling Functions for Multiuser Detection
  - Block
  - Recursive
- Conclusions

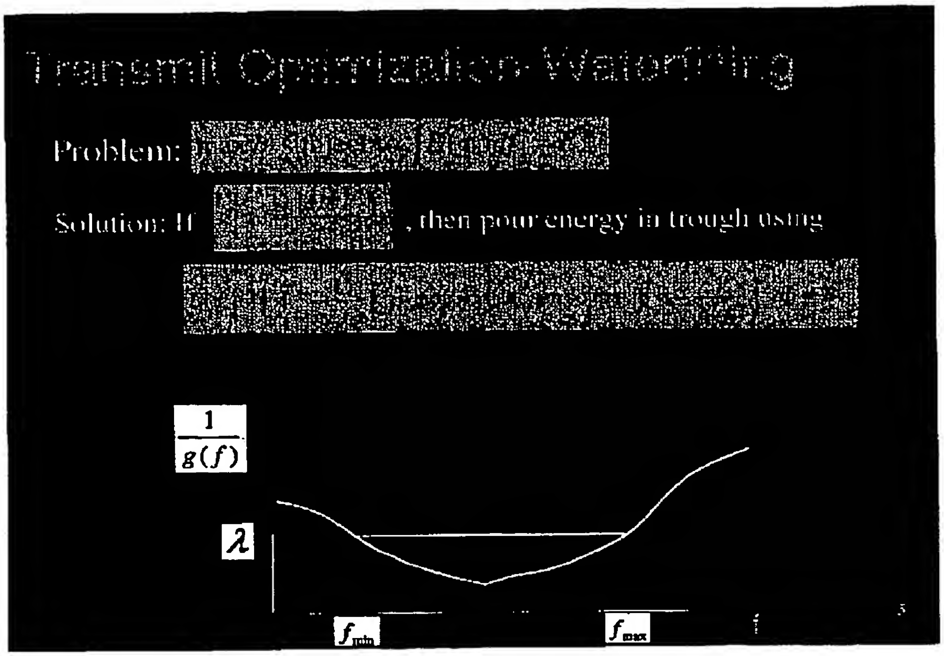
Motivation for Detecting Aggregate Interference

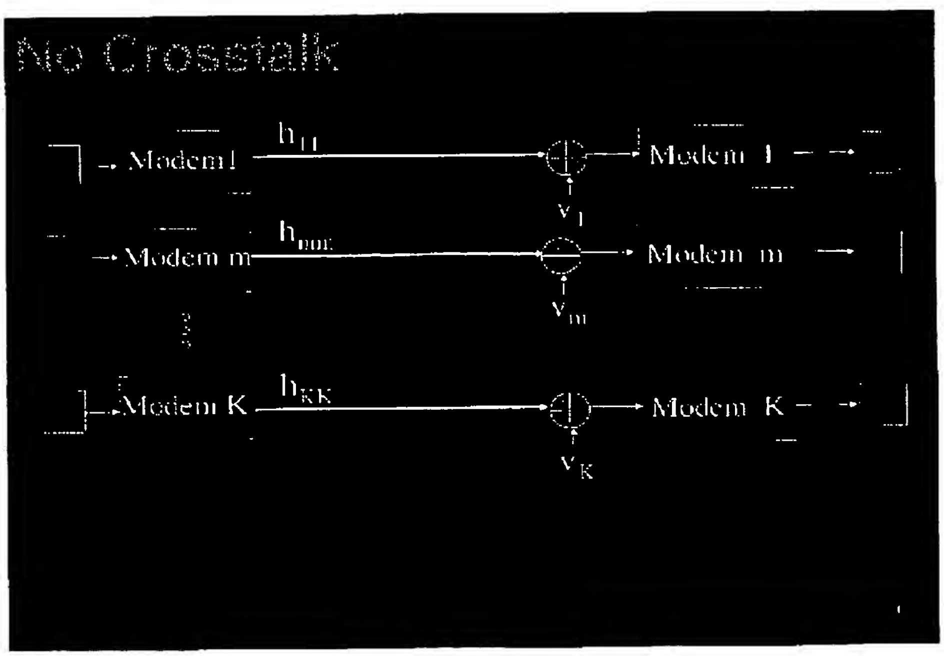
- Transmitter Optimization
  - Increase data rate and/or line reach
  - Reduce power consumption
- Track the changing environment conditions
  - React faster
  - Prevent modem retraining

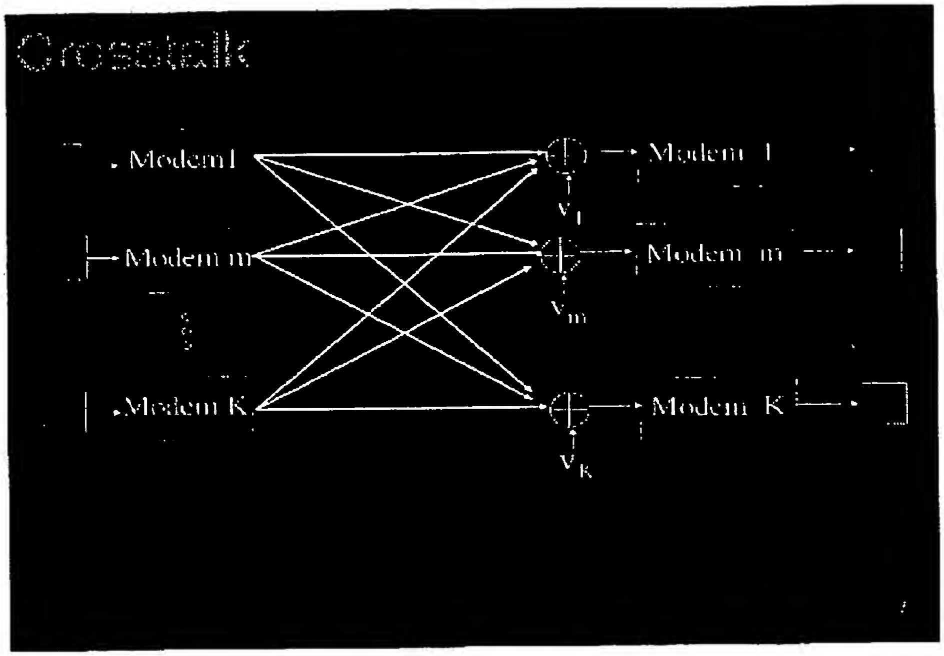
Multicarrier Transmission

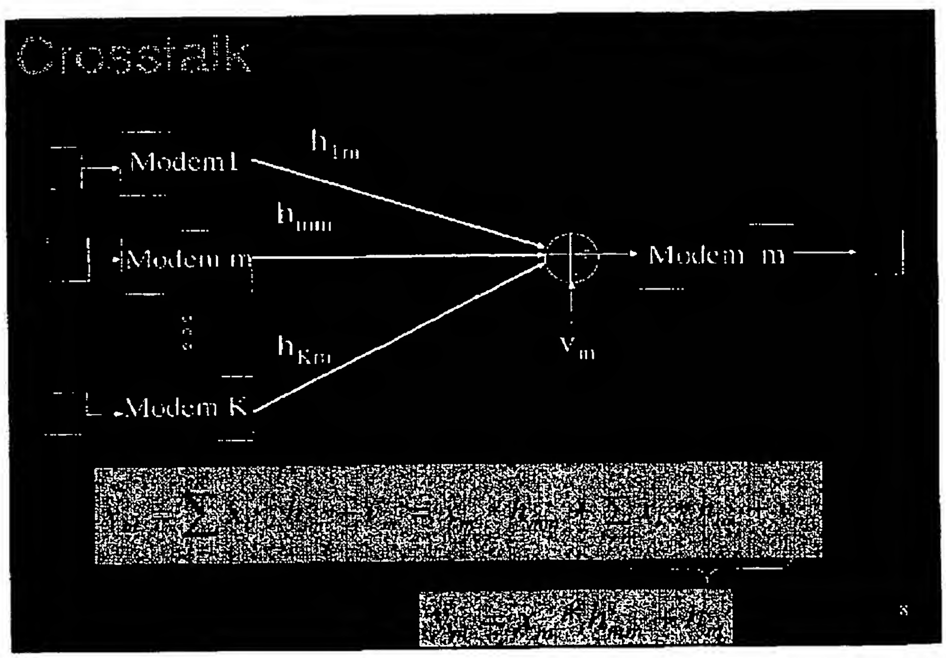


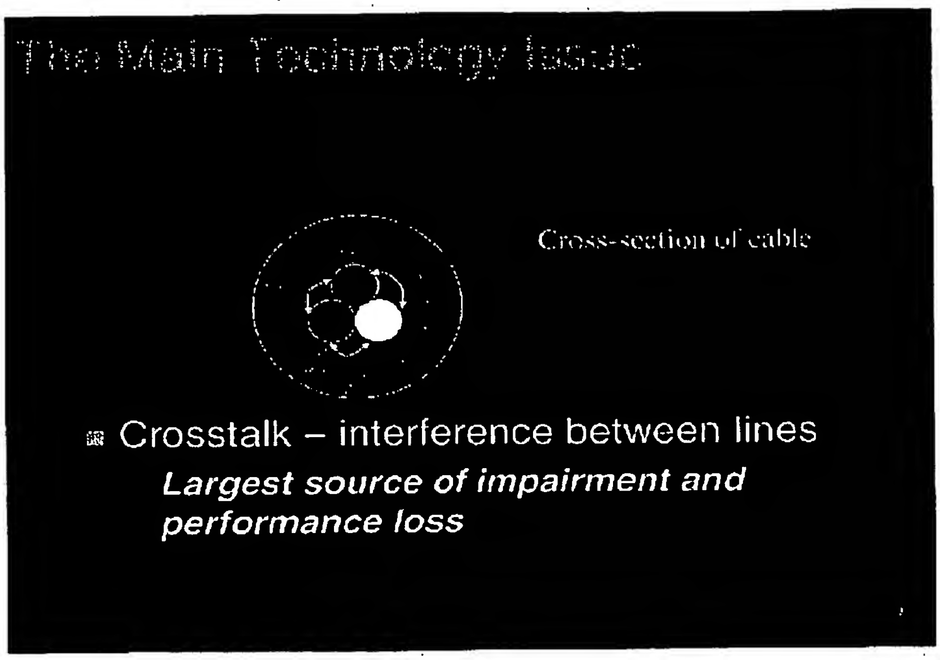
- Modulation done in frequency domain
- Transmit signal is IDFT of subchannel symbols
- Robust to frequency selective environments

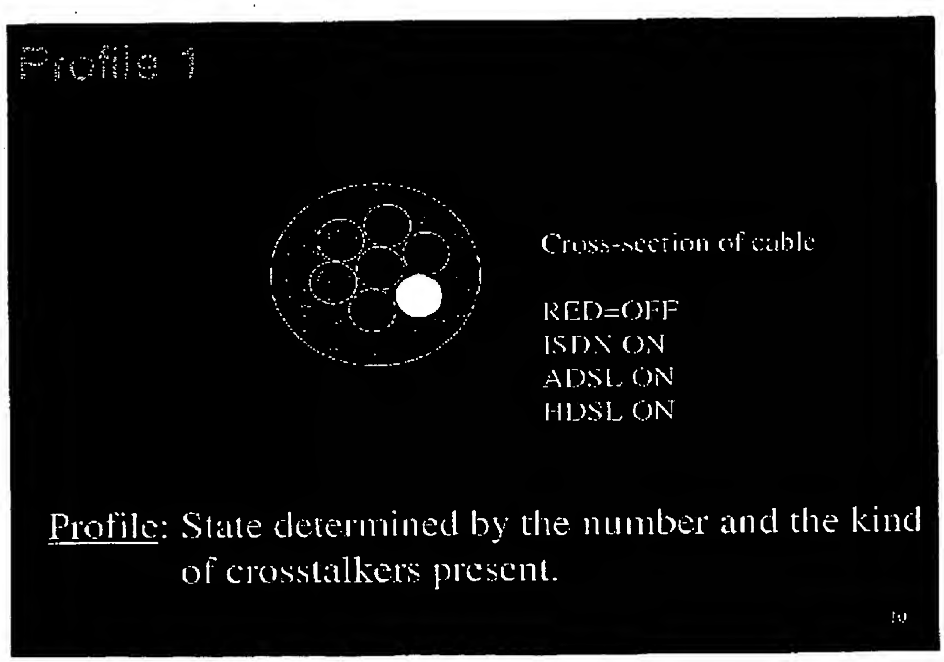

Transmit Optimization-Waterfilling
Problem:
Solution: If
, then pour energy in trough using
1
g(f)
λ
f
f min
f max

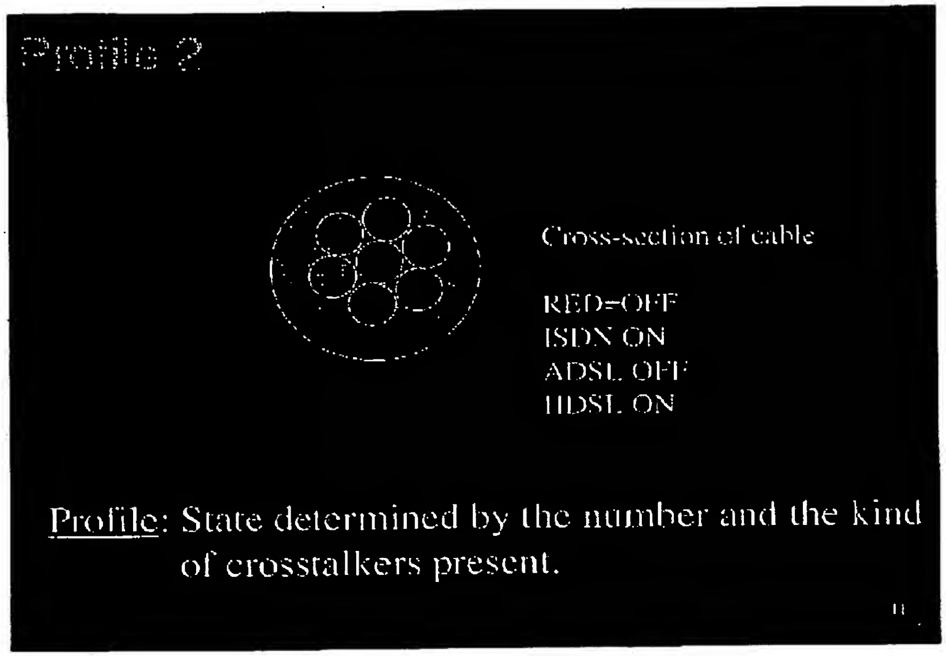

No Crosstalk
h11
Modem 1
v1
Modem 1
hmm
Modem m
vm
Modem m
hKK
Modem K
vK
Modem K

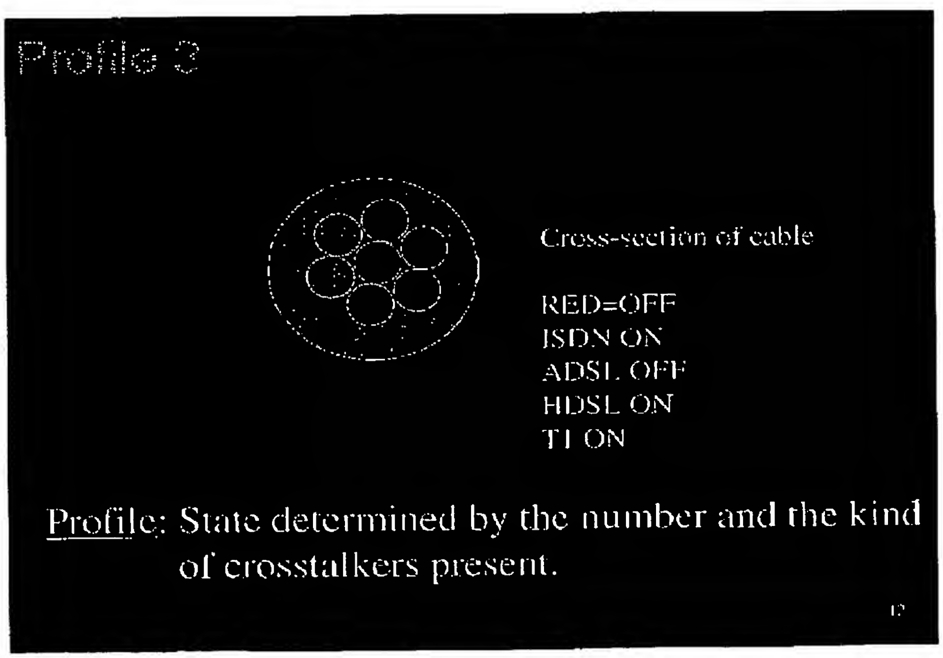

Crosstalk
Modem 1
Modem m
Modem K
Modem 1
Modem m
Modem K
v_1
v_m
v_K


Crosstalk
Modem 1
Modem m
Modem K
h_{1m}
h_{mm}
h_{Km}
Modem m
v_m

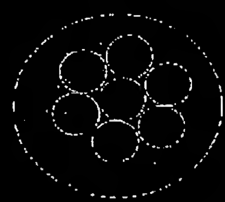

The Main Technology Issue
Cross-section of cable
Crosstalk – interference between lines
Largest source of impairment and performance loss


Profile 1
Cross-section of cable
RED=OFF
ISDN ON
ADSL ON
HDSL ON
Profile: State determined by the number and the kind of crosstalkers present.


Profile 2
Cross-section of cable
RED=OFF
ISDN ON
ADSL OFF
HDSL ON
Profile: State determined by the number and the kind of crosstalkers present.


Profile 3
Cross-section of cable
RED=OFF
ISDN ON
ADSL OFF
HDSL ON
T1 ON
Profile: State determined by the number and the kind of crosstalkers present.

Profile 4



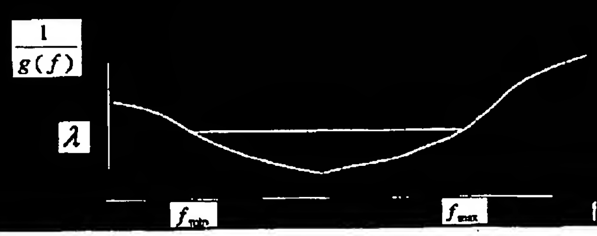
Cross-section of cable

RED-OFF
ISDN ON
ADSL OFF
HDSL ON
T1 ON
G. LITE ON

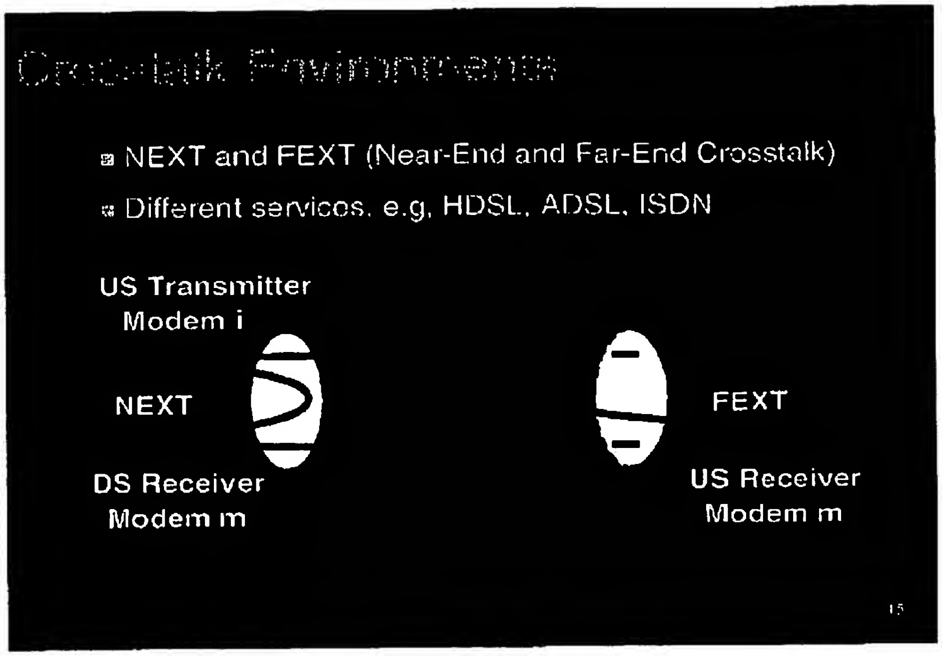
Profile: State determined by the number and the kind of crosstalkers present.

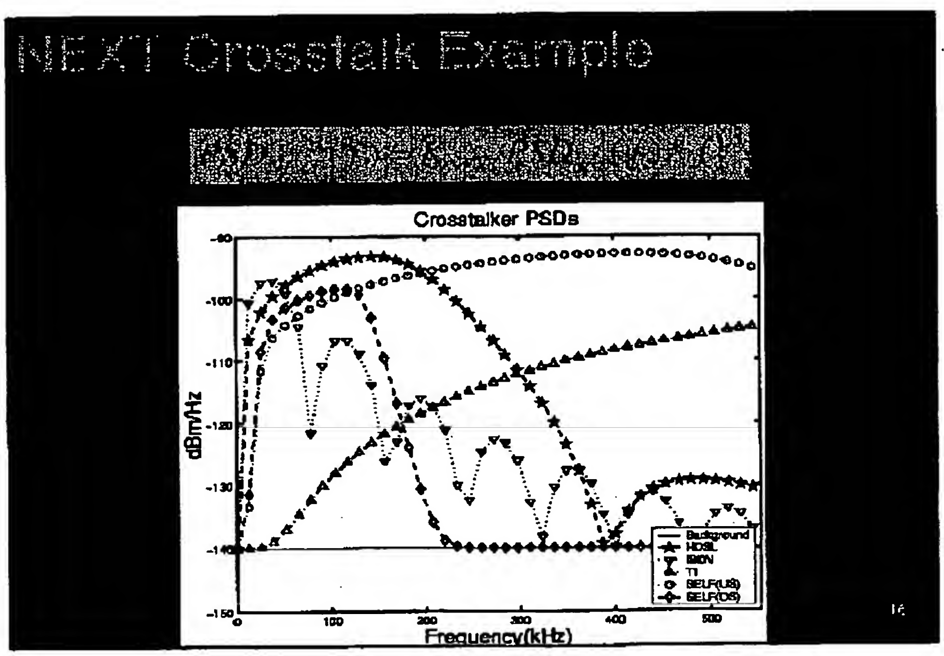
Profile

- Use profiles to track changing crosstalk conditions.
- Noise measurements matched to a set of profiles.
- Each profile has an optimized bit and energy table associated with it.

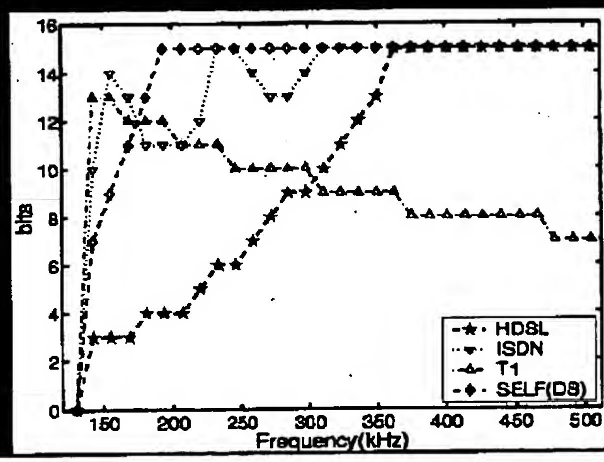


PAGE 15/48 * RCVD AT 3/16/2007 5:49:43 PM [Eastern Daylight Time] * SVR:USPTO-EFXRF-3/14 * DNIS:2738300 * CSID:414 431 1317 * DURATION (mm-ss):22-56


NEXT and FEXT (Near-End and Far-End Crosstalk)
Different services, e.g. HDSL, ADSL, ISDN
US Transmitter
Modem i
NEXT
DS Receiver
Modem m
FEXT
US Receiver
Modem m

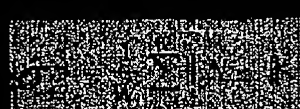

NEXT Crosstalk Example
Crosstalker PSDs
dBm/Hz
-90
-100
-110
-120
-130
-140
-150
0
100
200
300
400
500
Frequency(kHz)
Background
HDSL
ISDN
T1
SELF(US)
SELF(DS)

Bit Tables Example for Downstream (DS)



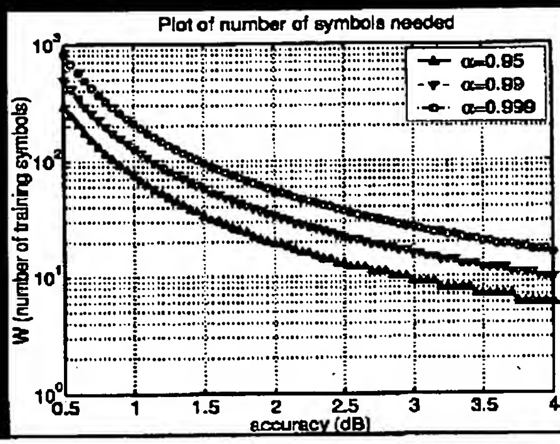
Acquiring a Profile

- Assume block stationarity
- For each tone i, estimate the crosstalk variance over a window of length W:



Number of Symbols Needed

Find smallest W such that: [illegible]



MAP Profile Detection

- Given a set of stored noise profiles, [illegible], minimize the probability of choosing an incorrect profile.
- Choose the profile that maximizes the a posteriori probability [illegible], where [illegible] has Gaussian pdf.
- Assuming a window of L multicarrier symbols, MAP algorithm becomes

[illegible]

where [illegible]

A Simple ML Example with L=1, P=3

noise power measurements are $[N_1^2, N_2^2, N_3^2] = [100,200,300]$

6 PROFILES

$$\sum_{l=1}^{3} \ln(\sigma_{j,l}^2) + \frac{N_l^2}{\sigma_{j,l}^2}]$$

j	$\sigma_{j,1}^2$	$\sigma_{j,2}^2$	$\sigma_{j,3}^2$
1.	.1	.2	.3
2.	1	2	3
3.	10	20	30
4.	50	100	150
5.	200	400	600
6.	1000	2000	3000

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A Simple ML Example with L=1, P=3

noise power measurements are $[N_1^2, N_2^2, N_3^2] = [100,200,300]$

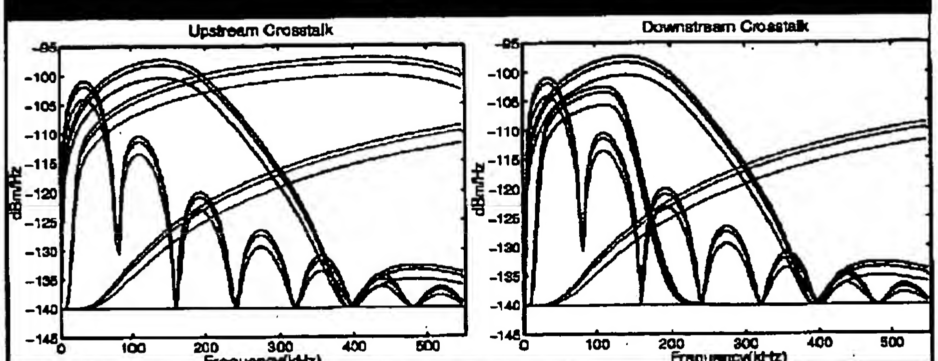
6 PROFILES

j	$\sigma_{j,1}^2$	$\sigma_{j,2}^2$	$\sigma_{j,3}^2$	$\sum_{l=1}^{3} \ln(\sigma_{j,l}^2) + \frac{N_l^2}{\sigma_{j,l}^2}]$
1.	.1	.2	.3	-5.1+3000 = 2994.9
2.	1	2	3	1.8+300 = 301.8
3.	10	20	30	8.7+30 = 38.7
4.	50	100	150	13.5+6 = 19.5
5.	200	400	600	17.7+1.5 = $\boxed{19.2}$
6.	1000	2000	3000	22.5+.6 = 23.1

Simulation Setting- ADSL (G.lite)

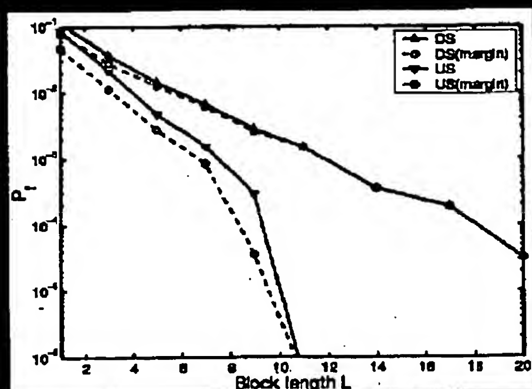
- 128 subchannels (32 for US, 96 for DS)
- Symbol period T=250 us
- 13 profiles for both upstream and downstream stored
  - 3 ISDN (3, 7, 10 users)
  - 3 HDSL (3, 7, 10 users)
  - 3 T1 (3, 7, 10 users)
  - 3 EC ADSL using G.lite (3,7,10 users)
  - Background Noise (-140dBm/Hz)

Profiles Used in Simulation



Simulation Results

- Probability of choosing an incorrect profile
- Probability of the chosen bit and energy table not meeting margin



- For this scenario, use of profiles allows for doubling of the data rate.

Advantages of Profiles

- Increase bit rates by having more profiles
  - Can have fast access to crosstalker activity—no need to transmit to worst case noise scenario
- Prevent modem failure by increasing block length L
- Low complexity

R is no. of profiles, T is the symbol period, P is number of tones.

When R=16, L=20, P=128, complexity = 2.3 MIPS

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  - <u>Block</u>
  - Recursive
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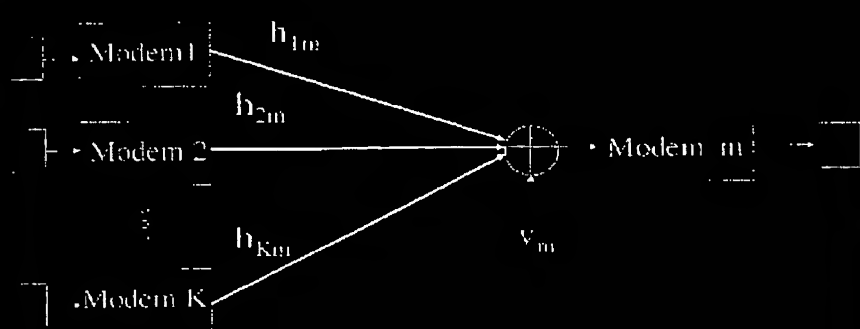
Crosstalk



Goal: Find h_{lm}

Motivation

- Multiuser Channel ID
  - Reliable channel and/or noise variance estimates for multiuser detection
  - Maintenance and diagnosis
  - Bandwidth efficient transmission
  - Desire to track the changing environment conditions
  - Estimates can be used for optimizing the transmitter
- Expectation Maximization (EM)
  - Reduce training overhead to practically 0

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Previous Work on Channel Estimation

- EM
  - Introduced (Dempster, Laird. 77)
  - SAGE (Fessler, Hero. 94)
  - SISO (Kaleh. Vallet. 94)
  - Recursive SISO (Zamiri-Jafarian, 97)
- MISO
  - Gaussian inputs (Feder, Weinstein. 88)
  - CDMA system (Bhashyam, Aazhang, 00)
- Finite Alphabet
  - MIMO system (Talwar, 96)
  - SISO OFDM (Zhou, Giannakis, 01)

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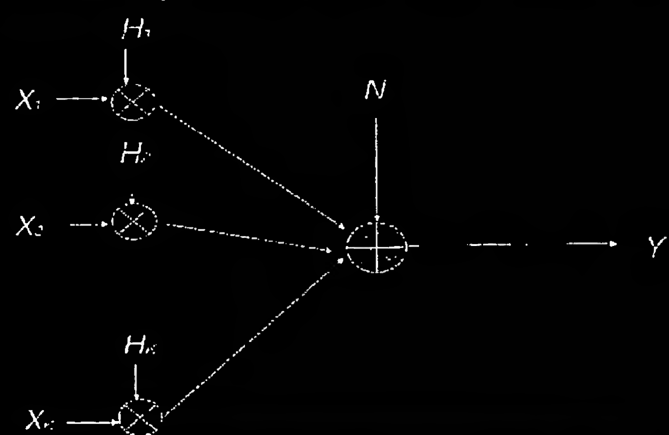
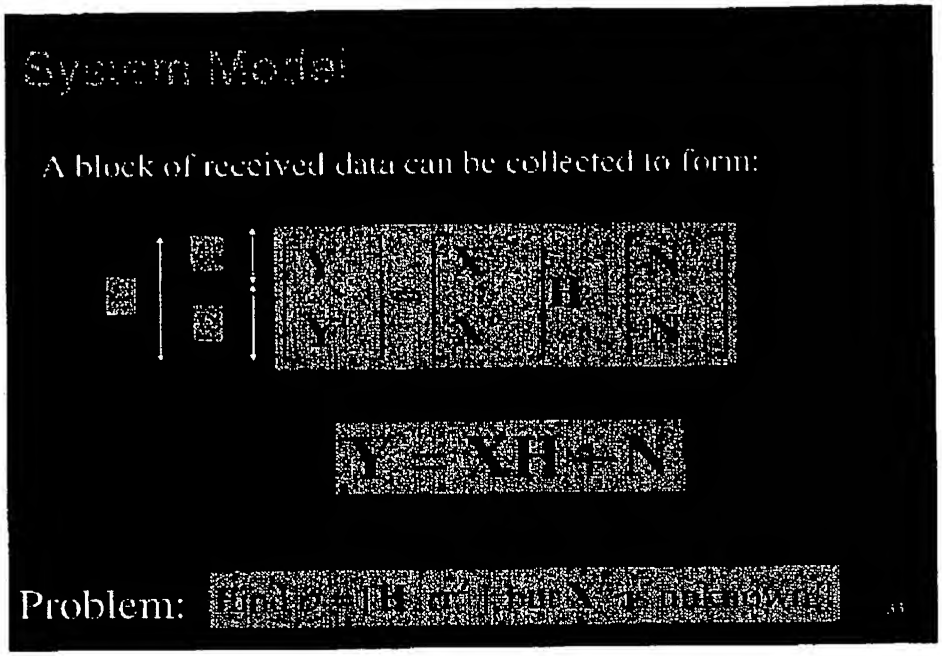
System Model

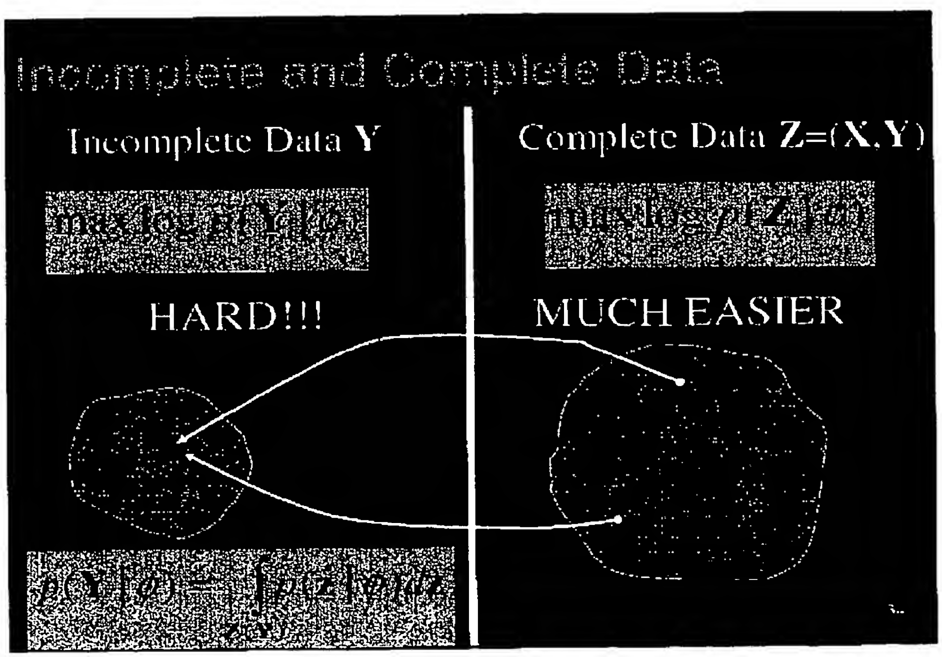
- Multiple access channel: K inputs, 1 output
- Modems are synchronized with same symbol period T
- Receiver knows the constellations of the transmitters.
- Channel and noise are block stationary

System Model with K Tx's

In multicarrier systems with K users, each subchannel appears




System Model
A block of received data can be collected to form:
Y = XH + N
Problem:


Incomplete and Complete Data
Incomplete Data Y
Complete Data Z=(X,Y)
HARD!!!
MUCH EASIER

Initialization of EM

- By means of training, one can find estimates:

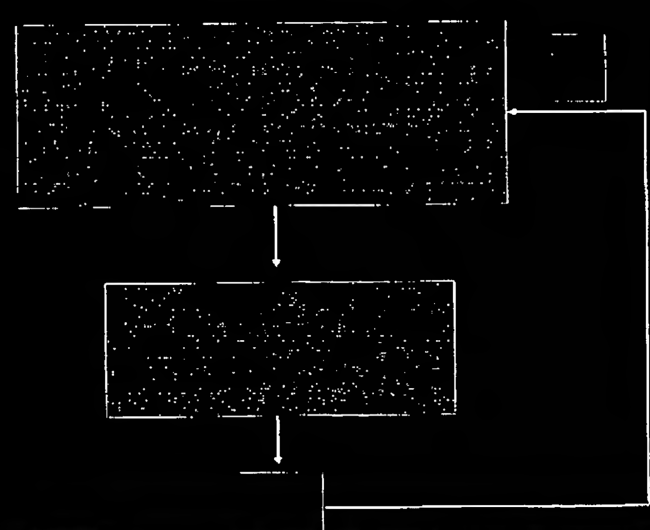
$$\mathbf{H}_0 = (\mathbf{X}^*\mathbf{X})^{-1}\mathbf{X}^*\mathbf{Y}$$

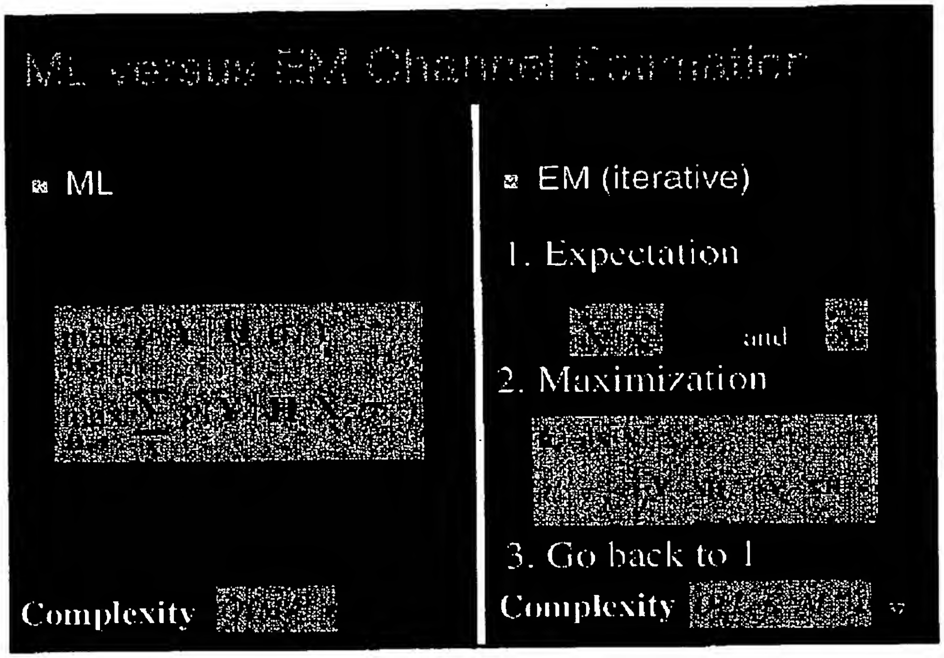
[illegible]

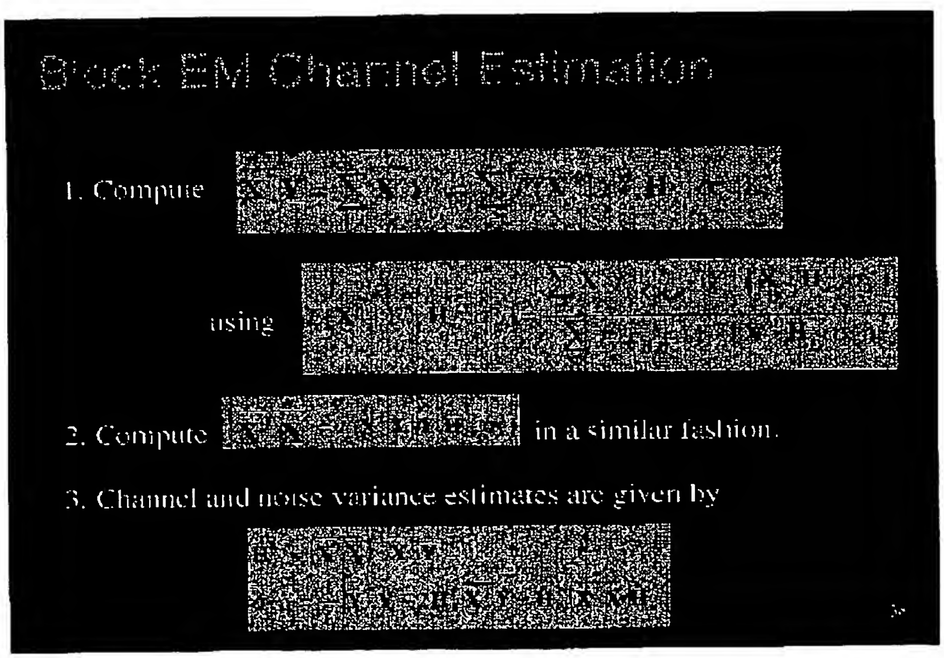
- The error in the channel estimate is given by

$$\delta = \mathbf{H} - \mathbf{H}_0 \sim \mathcal{N}(0, \sigma^2(\mathbf{X}^*\mathbf{X})^{-1})$$

Overview of EM




ML versus EM Channel Estimation
ML
EM (iterative)
1. Expectation
and
2. Maximization
3. Go back to 1
Complexity
Complexity


Block EM Channel Estimation
1. Compute
using
2. Compute
in a similar fashion.
3. Channel and noise variance estimates are given by

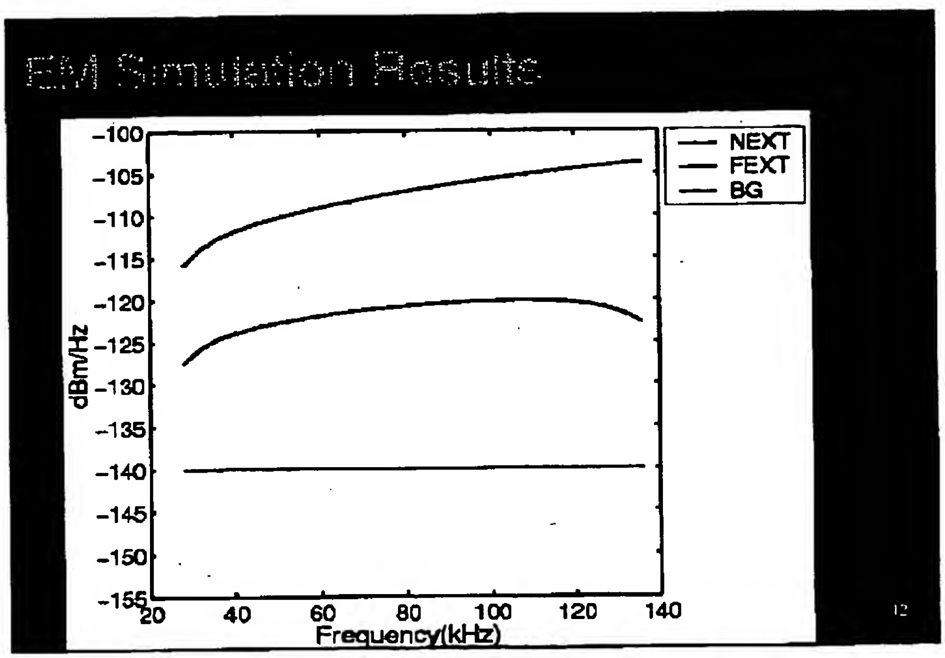
Advantages of EM

- Takes advantage of finite alphabet property of transmit signal.
- Increases likelihood at every iteration and guaranteed to converge.
- Provides MMSE estimate of transmit data.

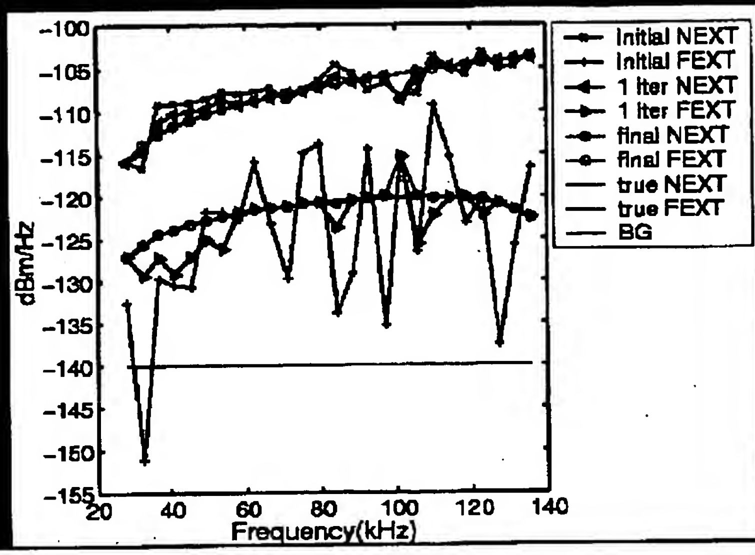
Let's take a trip to Japan

Simulation Setup

- ADSL-DBM modem
  - 1 NEXT (SSDSL) and
  - 1 FEXT (ADSL)
- 500 m line FEXT source
- Initial condition acquired from previous block
- 10 ms of data (Ltr=0, L=40)



EM Simulation Results



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- Aggregate Interference
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  - Block
  - Recursive
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Motivation

- Eliminates delay
- Reduces storage
- Track time-variant parameters in an adaptive manner
- Block stationary assumption no longer needed

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MISO Recursive EM

1. Find [illegible] and [illegible]
2. Compute [illegible]
3. Update

[illegible]

Complexity [illegible]

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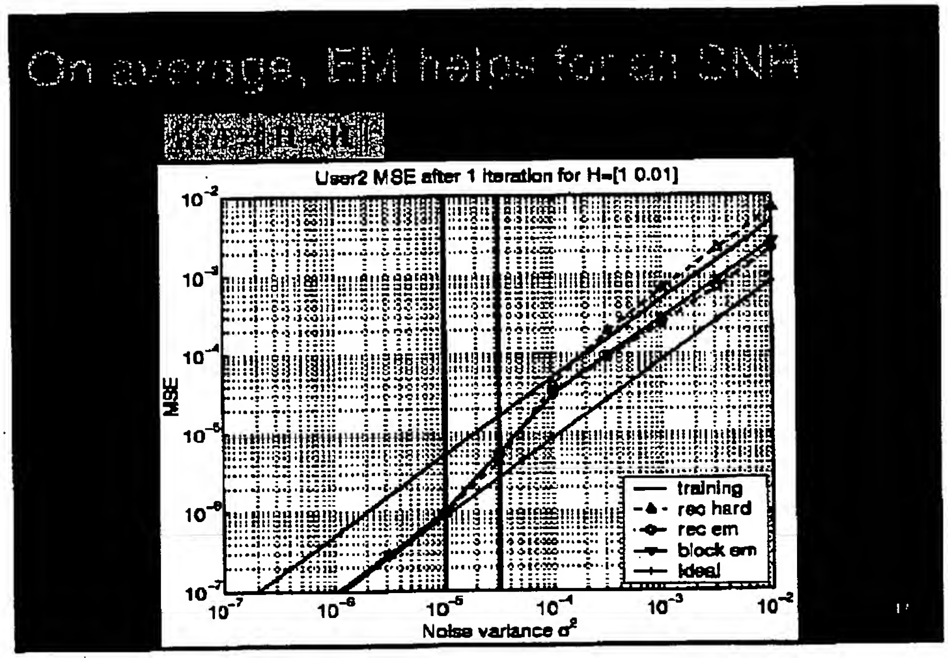
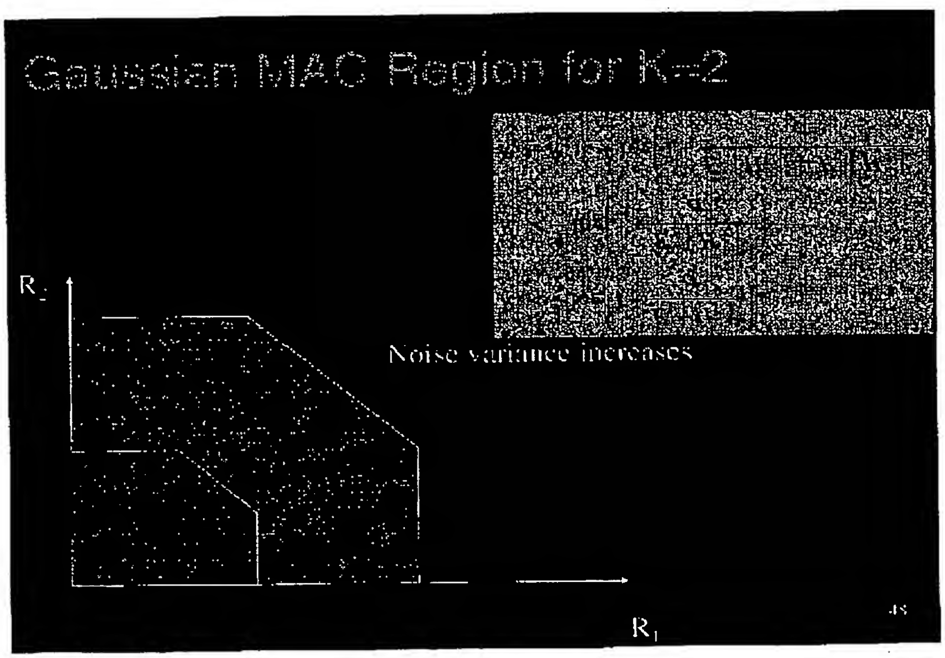
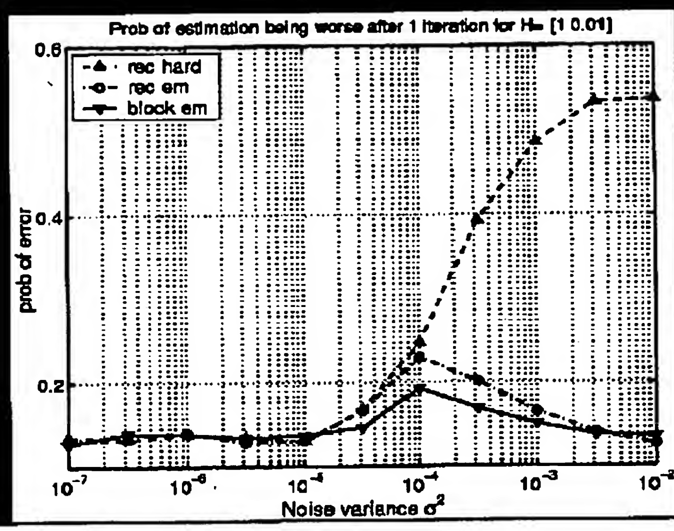

On average, EM helps for all SNR
User2 MSE after 1 iteration for H=[1 0.01]
MSE
Noise variance σ^2
training
rec hard
rec em
block em
ideal


Gaussian MAC Region for K=2
R_2
Noise variance increases
R_1

Probability that EM makes MSE worse than [illegible] training



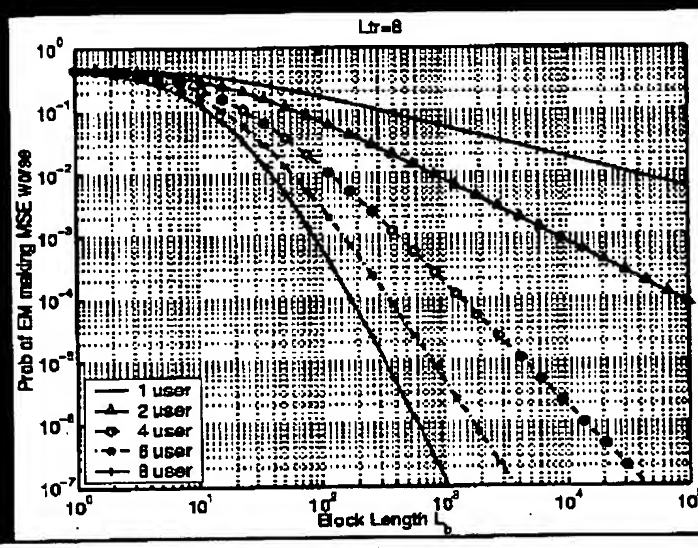
Error Floor Analysis for EM w/ training

If each user has equal energy [illegible], and we assume that

- [illegible]
- Training portion and training+blind are independent then:

[illegible]

Error Floor for Different K



Comparison with Modified LMS (MLMS)

Multiuser Channel ID

[illegible]

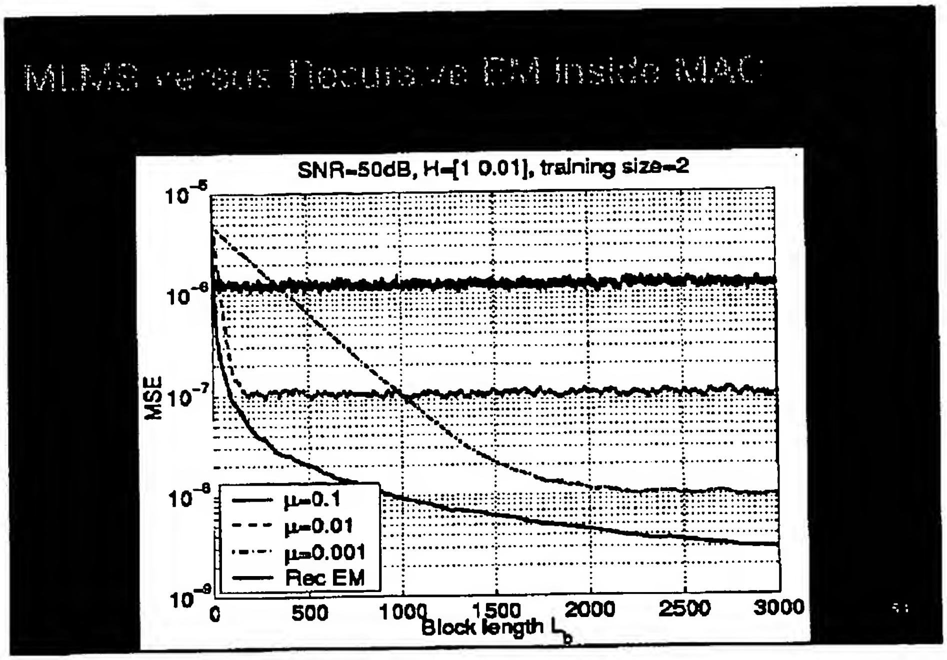
[illegible]

Advantages of MLMS over EM:

- No need to compute second order statistics.
- Reduces complexity from [illegible] to [illegible]

Disadvantages

- Convergence speed, misadjustment



Summary of Contributions

- Identified crosstalk spectrum using accurate and low complexity algorithm
  - Higher data rates
  - 4s Profile 5ms
- Obtained multiuser ML channel and noise estimates
  - Soft decisions better than hard decisions
  - Improved training estimates outside the MAC region
- Developed recursive solution
  - Less storage and delay
- Additional work
  - Extension to MIMO systems
  - Application to coded systems

Papers

- Aldana, Carvalho, Cioffi, "Channel Estimation for Multicarrier Multiple Input, Single Output Systems using the EM Algorithm", to be submitted to Trans Signal Processing
- Aldana, Cioffi "Channel Tracking for Multiple Input, Single Output Systems using the EM Algorithm", ICC 2001.
- Aldana, Salvekar, Tellado, Cioffi, "MAP Noise Profile Matching for Multicarrier Systems", ICT 2001.
- Aldana, Salvekar, Tellado, Cioffi, "Accurate Noise Estimates in Multicarrier Systems", Fall VTC 2000.
- Salvekar, Aldana, Carvalho, Cioffi, "Crosstalk Profile Detection for use in Multiuser Detection", ICC 2001.
- Zeng, Aldana, Salvekar, Cioffi, "Crosstalk Identification in xDSL systems", IEEE Journal on Selected Areas of Communications.
- Salvekar, Aldana, Tellado, Cioffi, "Peak-to-Average Power Ratio Reduction for Block Transmission Systems in the Presence of Transmit Filtering", ICC 2001.
- Salvekar, Aldana, Tellado, Cioffi, "Channel Gain Change Detection and Channel Profile Selection in a Multicarrier System", Globecom 99.

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Acknowledgment

- Advisor: Prof. Cioffi
- Associate advisor: Prof. Cox
- PhD Oral Committee: Prof. Tobagi and Prof. Gill
- Joice
- Family
- Wonderful Friends

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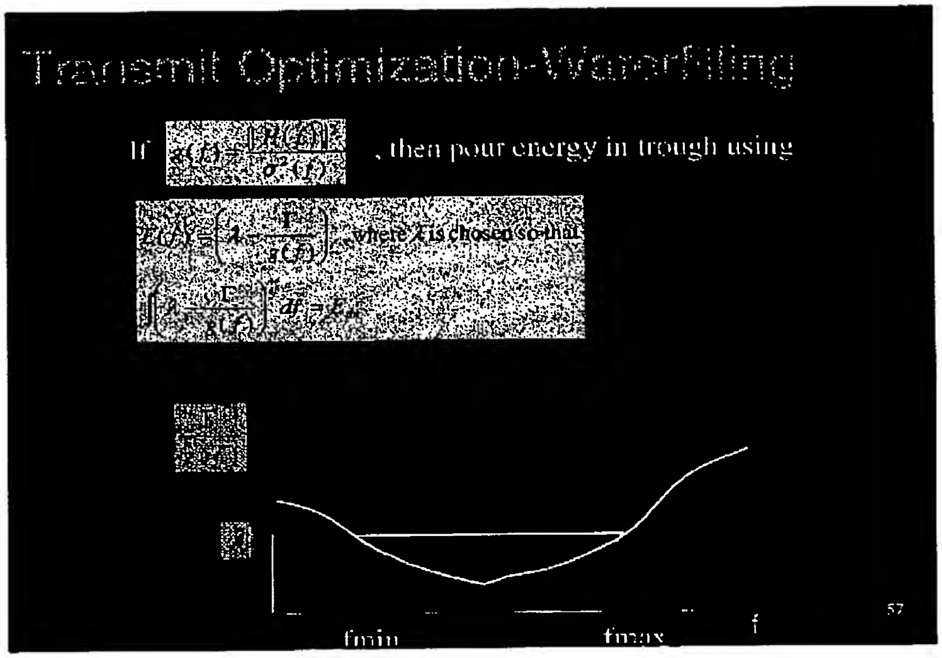
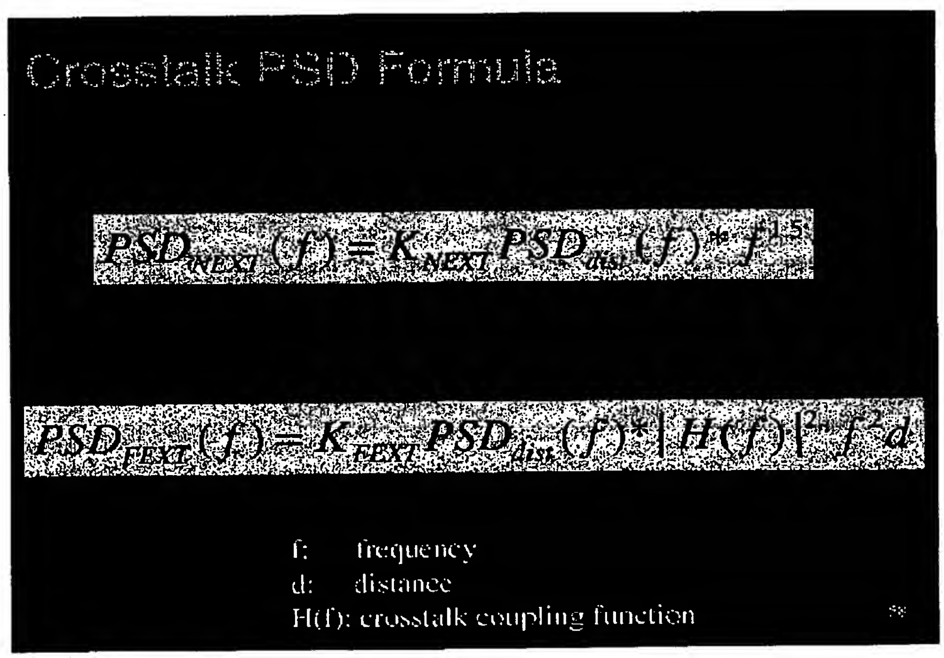

Transmit Optimization-WaterFilling
If $g(f)=\frac{|H(f)|^2}{\sigma^2(f)}$, then pour energy in trough using
$E(f)=\left(\lambda-\frac{\Gamma}{g(f)}\right)^+$ where λ is chosen so that
$\int\left(\lambda-\frac{\Gamma}{g(f)}\right)^+ df = E_x$
fmin
fmax
f
57


Crosstalk PSD Formula
$PSD_{NEXT}(f)=K_{NEXT}\,PSD_{dist}(f)*f^{1.5}$
$PSD_{FEXT}(f)=K_{FEXT}\,PSD_{dist}(f)*|H(f)|^2*f^2 d$
f: frequency
d: distance
H(f): crosstalk coupling function
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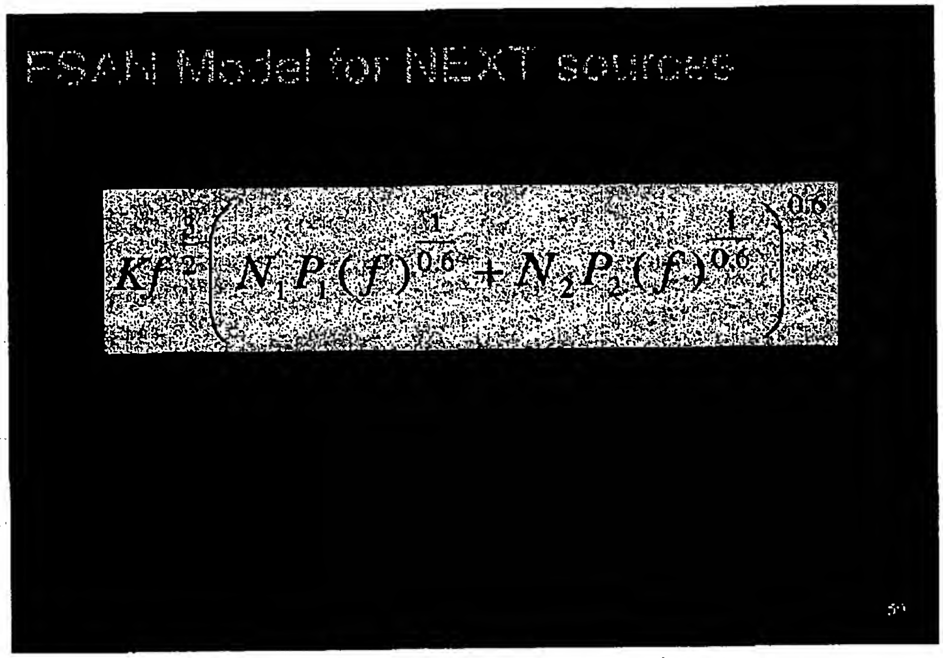
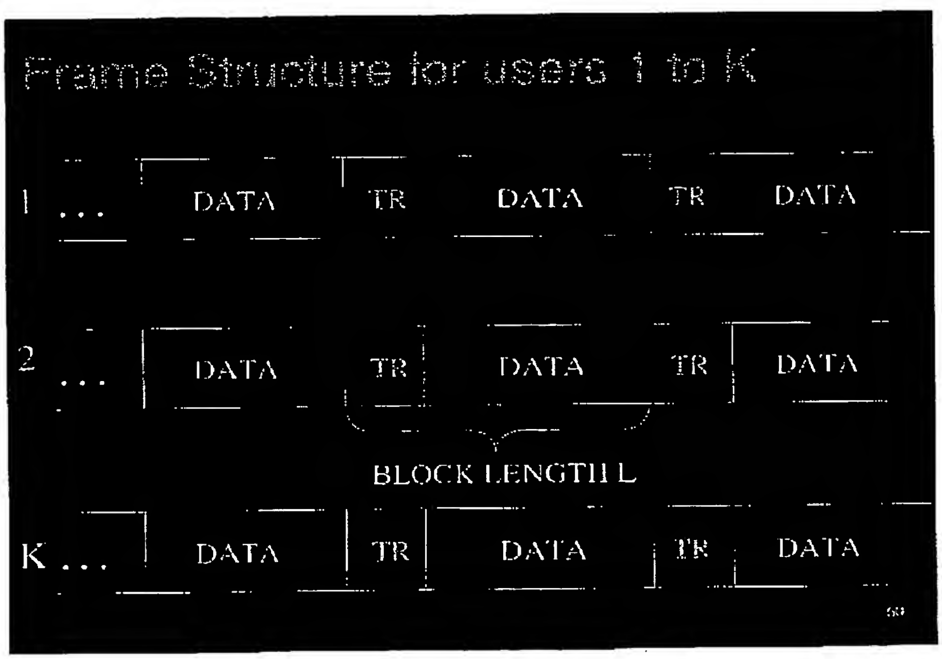
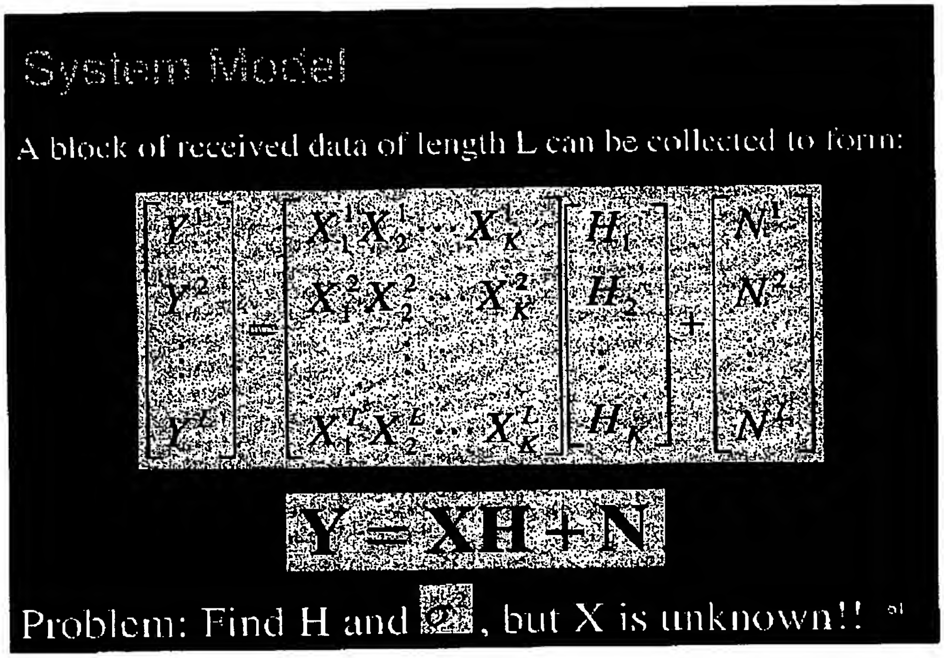
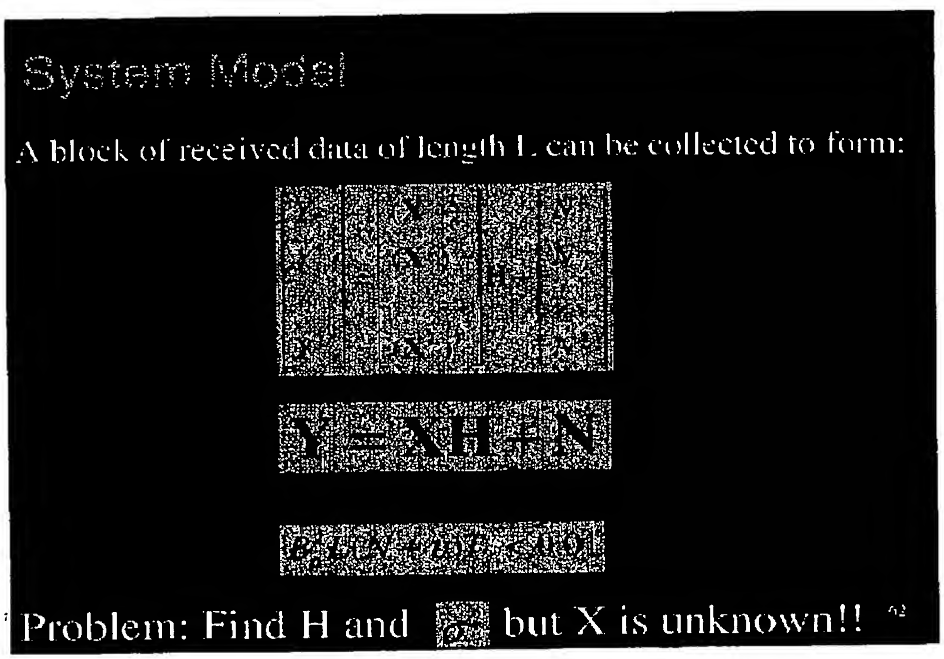

FSAN Model for NEXT sources
$$Kf^{\frac{3}{2}}\left(N_1P_1(f)^{\frac{1}{0.6}}+N_2P_2(f)^{\frac{1}{0.6}}\right)^{0.6}$$


Frame Structure for users 1 to K
1 ...
DATA
TR
DATA
TR
DATA
2 ...
DATA
TR
DATA
TR
DATA
BLOCK LENGTH L
K ...
DATA
TR
DATA
TR
DATA


System Model
A block of received data of length L can be collected to form:
Y = XH + N
Problem: Find H and σ², but X is unknown!!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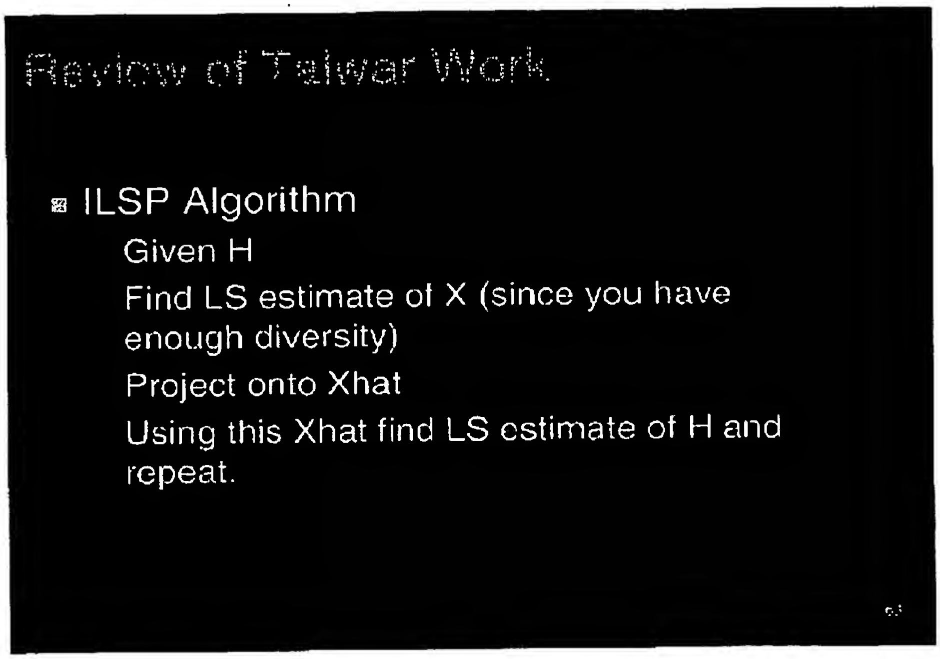
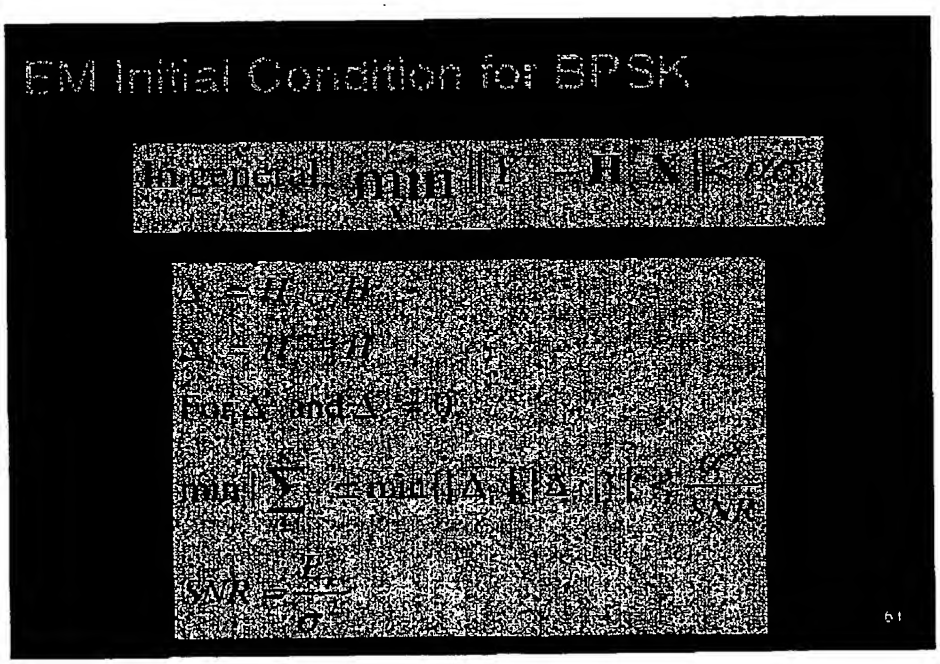
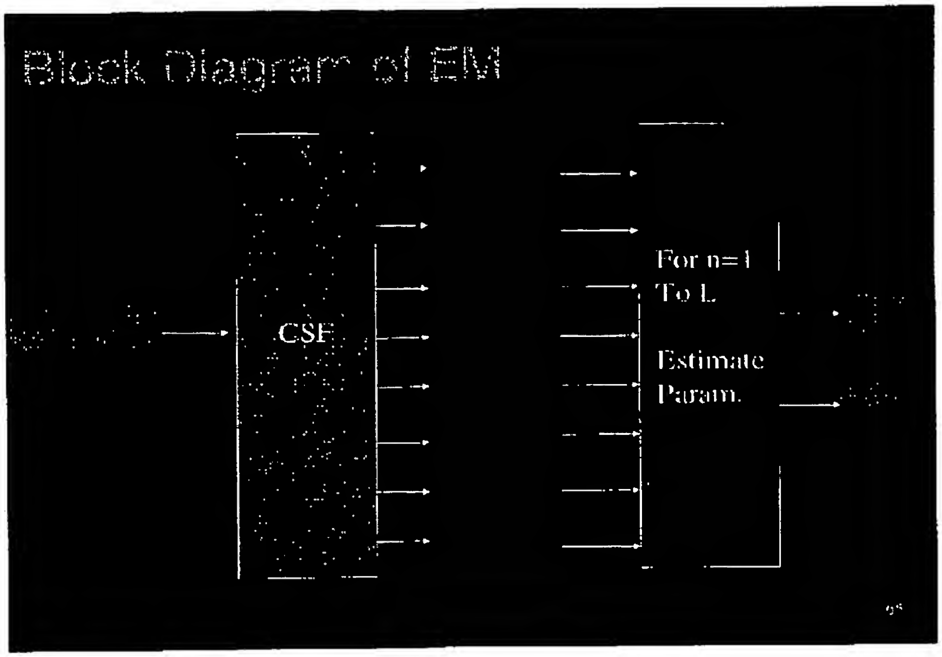
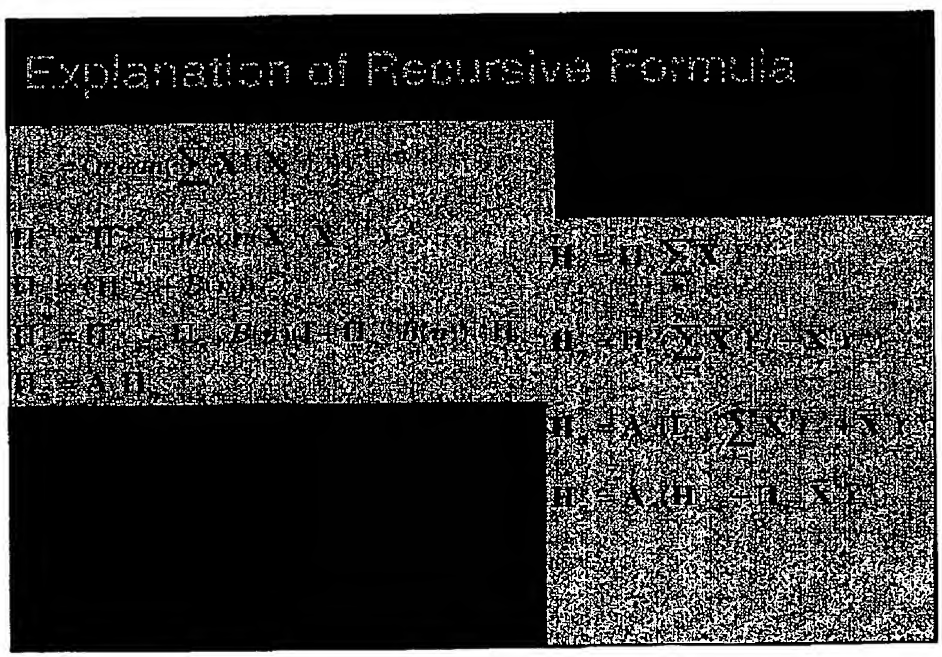
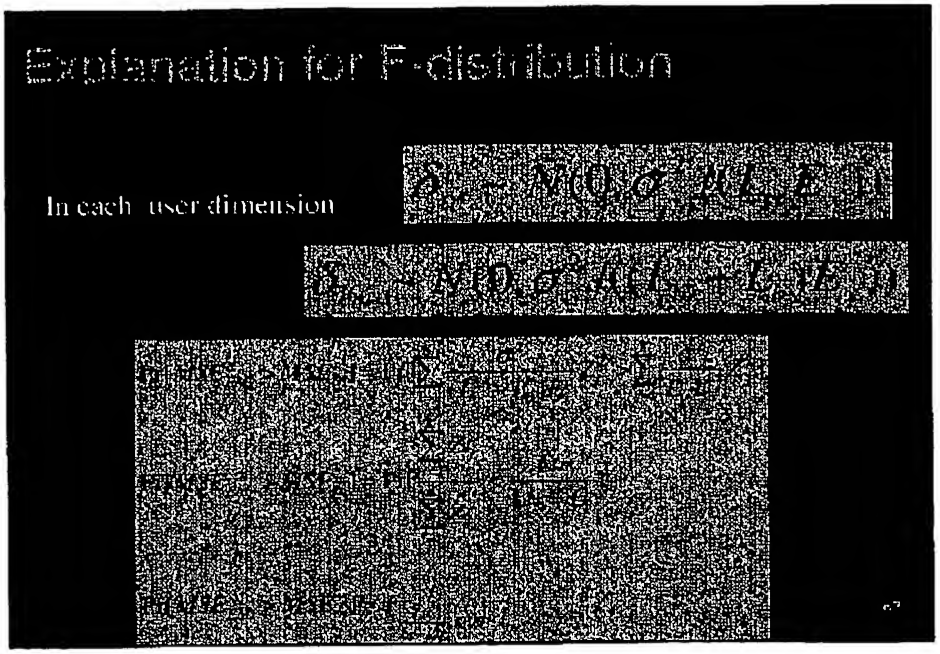
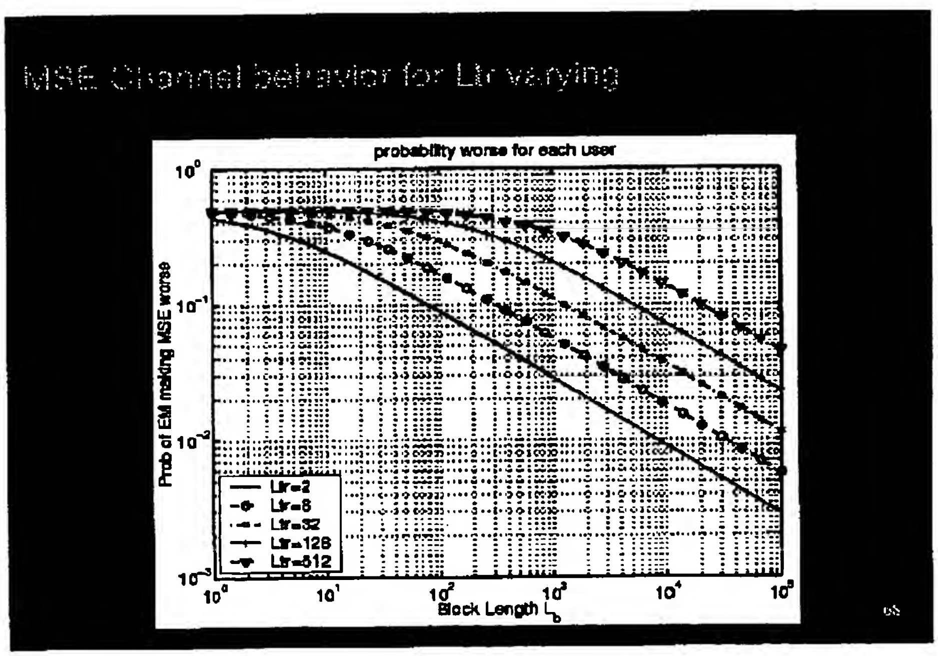

Review of Talwar Work
ILSP Algorithm
Given H
Find LS estimate of X (since you have enough diversity)
Project onto Xhat
Using this Xhat find LS estimate of H and repeat.

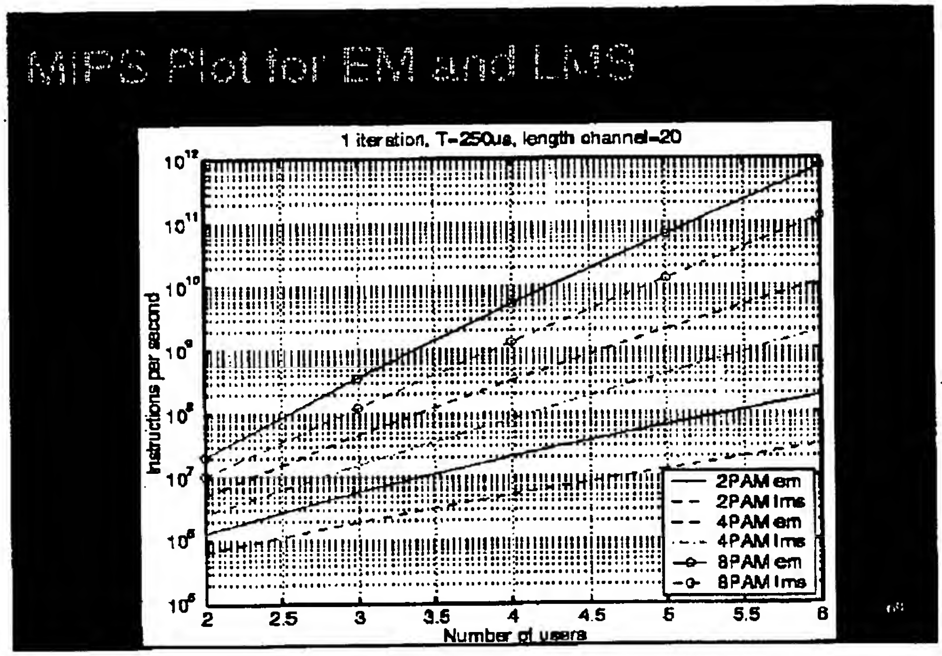

EM Initial Condition for BPSK
In general

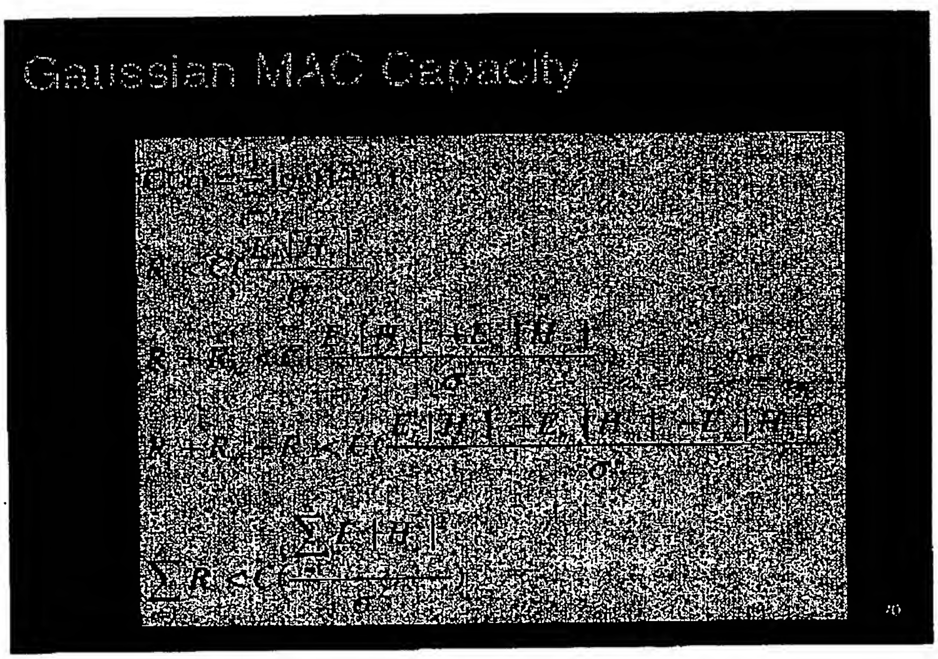

Block Diagram of EM
CSF
For n=1
To L
Estimate
Param.

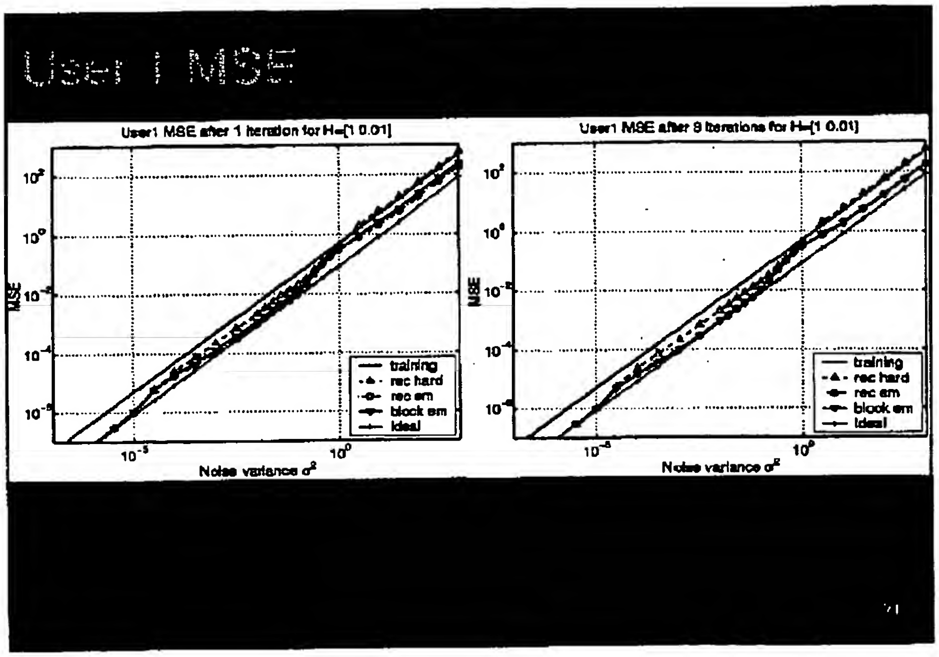

Explanation of Recursive Formula

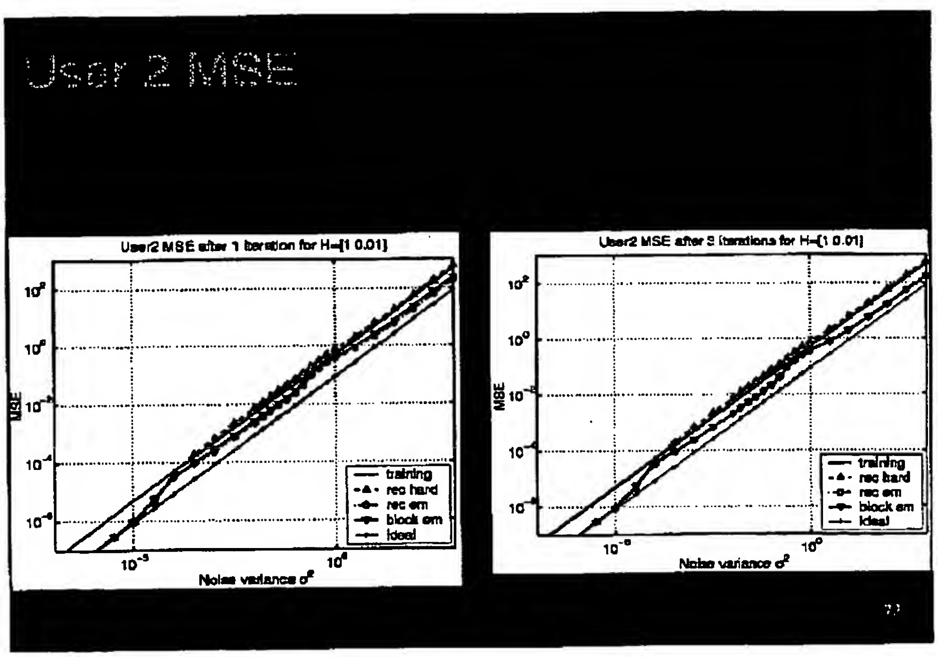

Explanation for F-distribution
In each user dimension

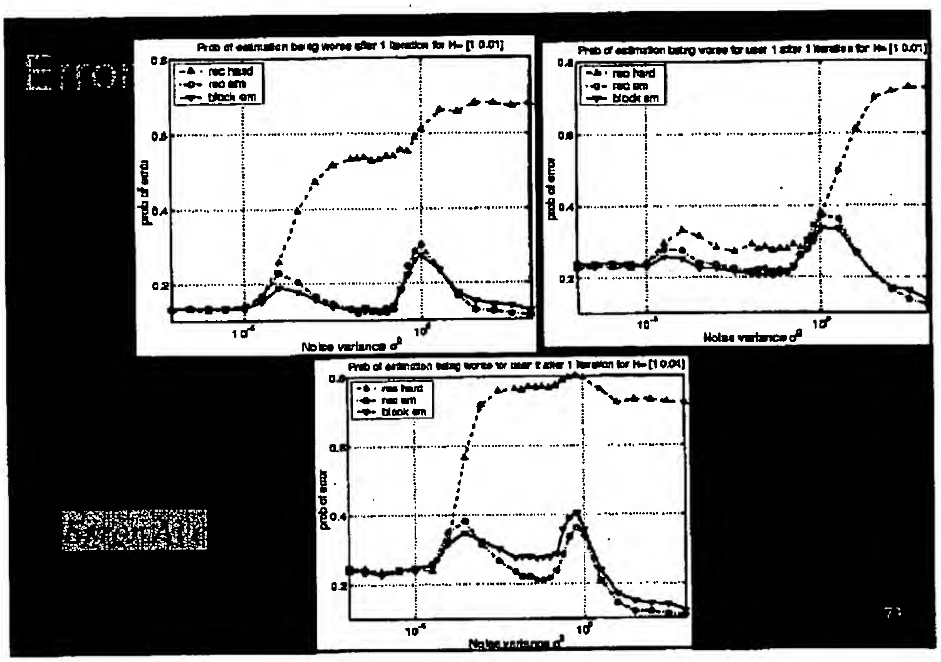

MSE Channel behavior for Ltr varying
probability worse for each user
Prob of EM making MSE worse
Block Length L_b
Ltr=2
Ltr=8
Ltr=32
Ltr=128
Ltr=512
10^0
10^{-1}
10^{-2}
10^{-3}
10^0
10^1
10^2
10^3
10^4
10^5

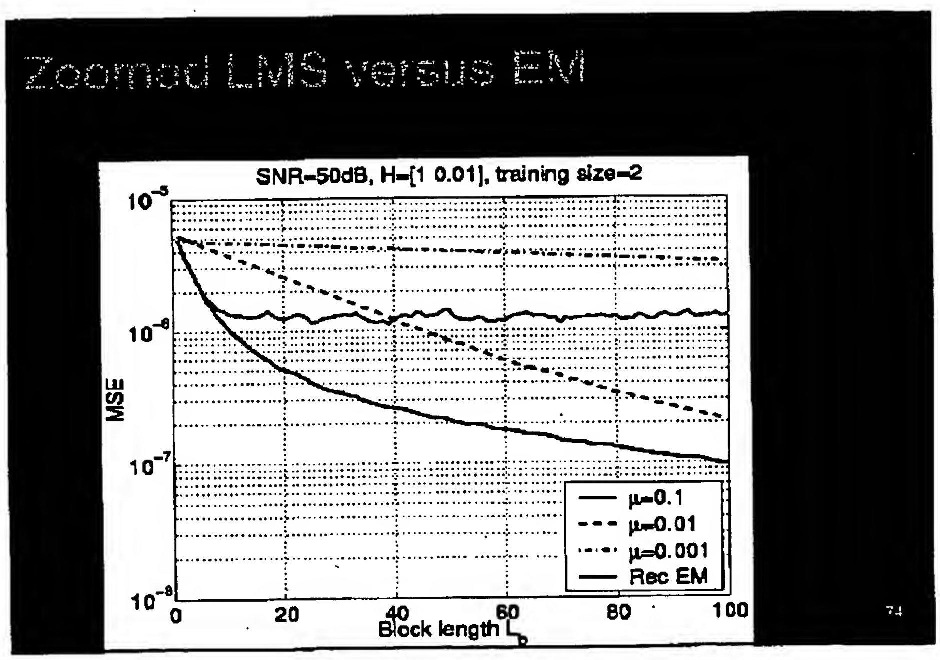

MIPS Plot for EM and LMS
1 iteration, T=250us, length channel=20
Instructions per second
Number of users
2PAM em
2PAM lms
4PAM em
4PAM lms
8PAM em
8PAM lms

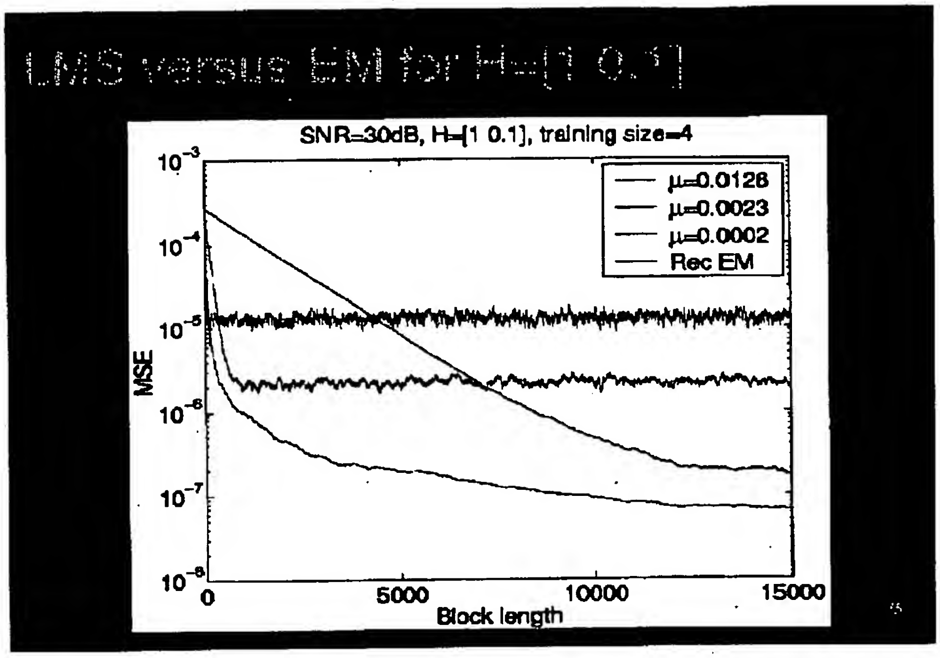

Gaussian MAC Capacity

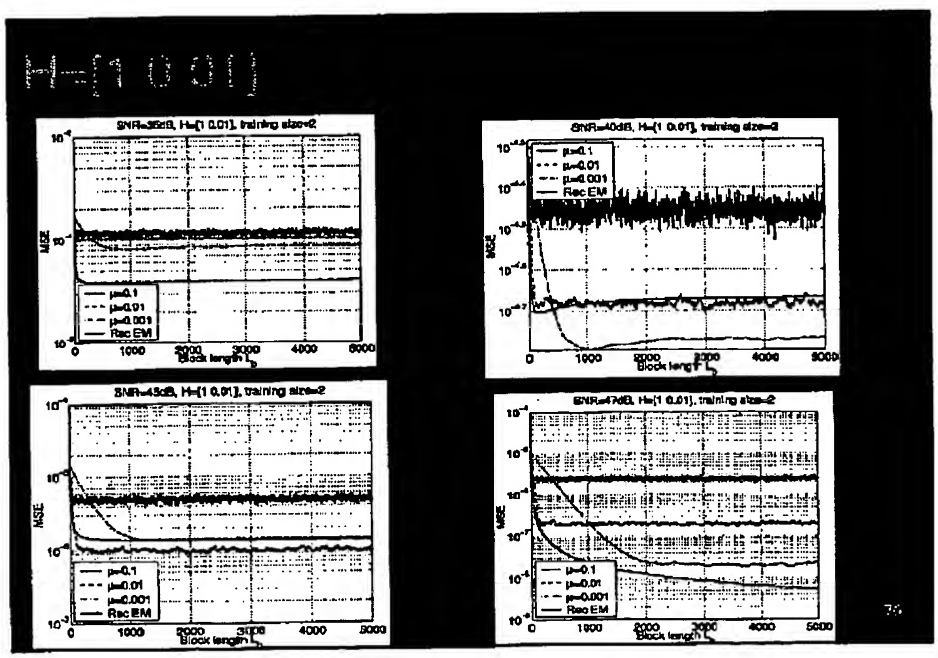

User 1 MSE
User1 MSE after 1 iteration for H=[1 0.01]
User1 MSE after 8 iterations for H=[1 0.01]
MSE
Noise variance σ²
training
rec hard
rec em
block em
ideal

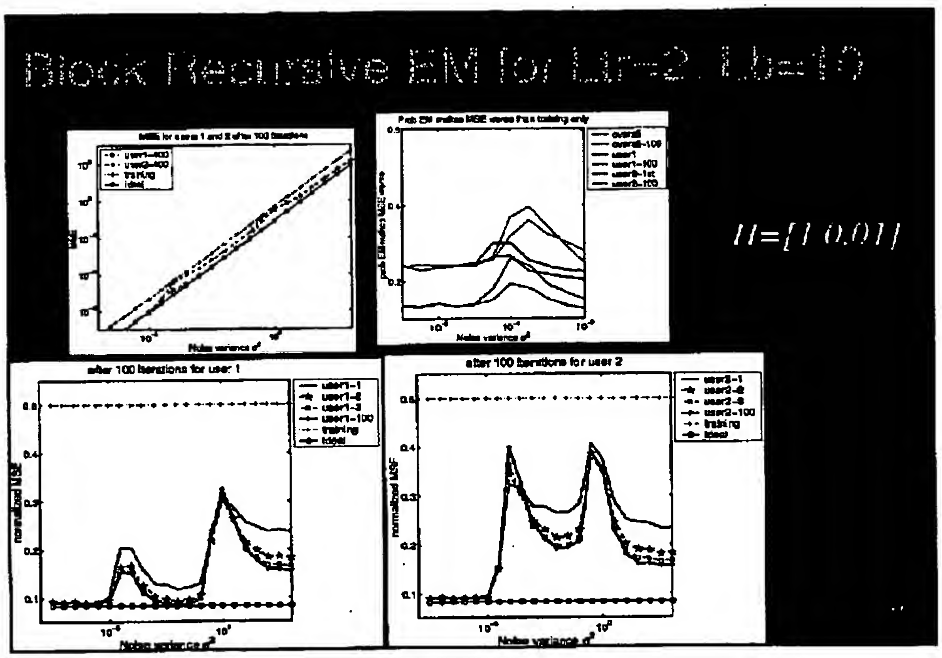

User 2 MSE
User2 MSE after 1 iteration for H=[1 0.01]
User2 MSE after 8 iterations for H=[1 0.01]
MSE
Noise variance σ²
training
rec hard
rec em
block em
ideal

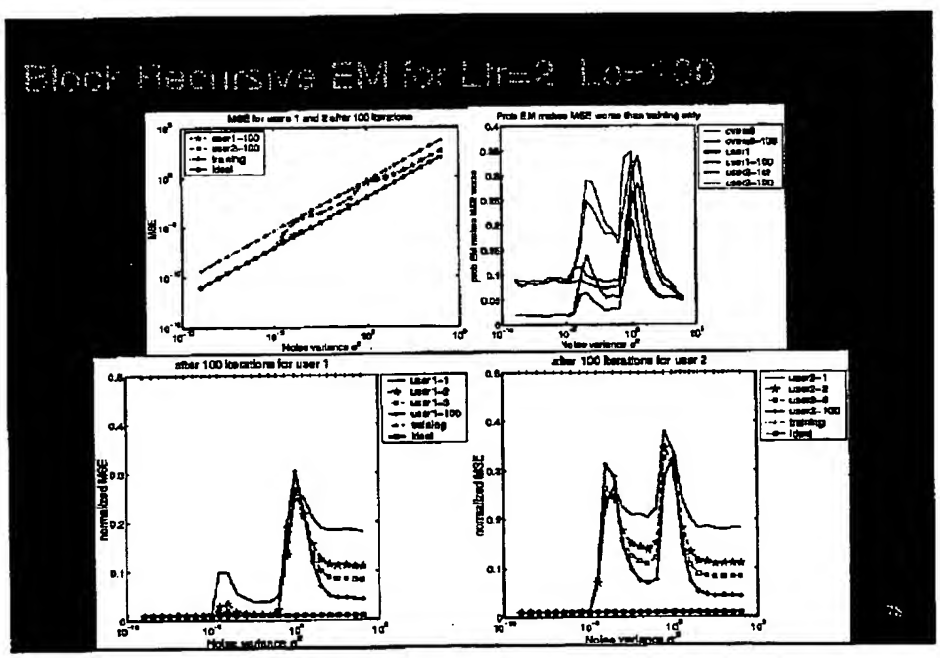

rec hard
rec em
block em
prob of error
Noise variance σ²
73

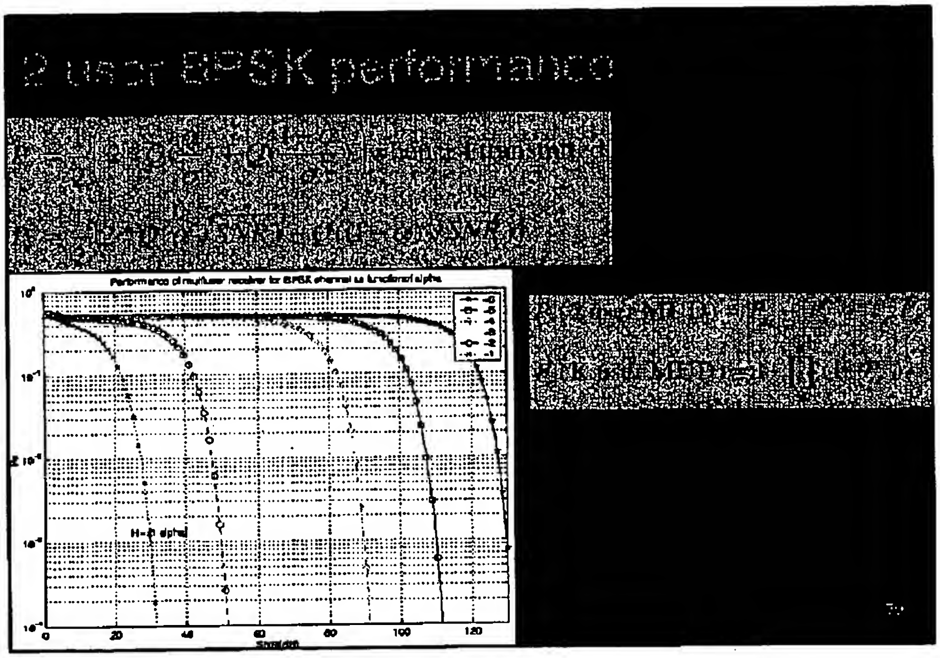

Zoomed LMS versus EM
SNR=50dB, H=[1 0.01], training size=2
MSE
Block length L_b
μ=0.1
μ=0.01
μ=0.001
Rec EM
74

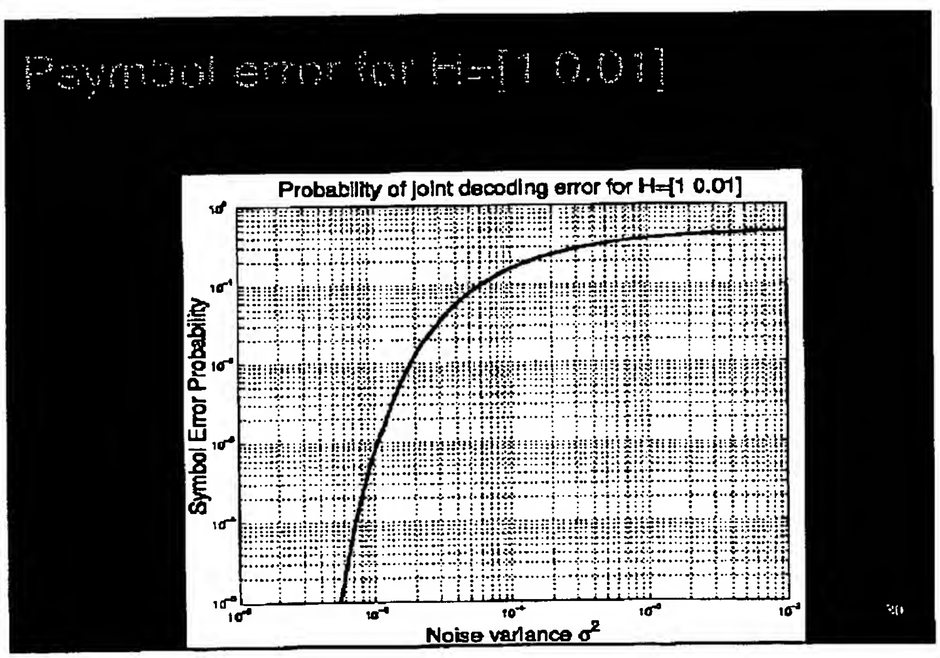

LMS versus EM for H=[1 0.1]
SNR=30dB, H=[1 0.1], training size=4
μ=0.0128
μ=0.0023
μ=0.0002
Rec EM
MSE
Block length
0
5000
10000
15000


H=[1 0.01]
μ=0.1
μ=0.01
μ=0.001
Rec EM
MSE
Block length


Block Recursive EM for Ltr=2, Lb=10
H=[1 0.01]
after 100 iterations for user 1
after 100 iterations for user 2
normalized MSE
Noise variance σ²


Block Recursive EM for Ltr=2, Lb=100
after 100 iterations for user 1
after 100 iterations for user 2
normalized MSE
Noise variance σ²


2 user BPSK performance
H=[1 alpha]


Psymbol error for H=[1 0.01]
Probability of joint decoding error for H=[1 0.01]
Symbol Error Probability
Noise variance σ^2